Title: METHOD FOR QUADRATURE-BIAS COMPENSATION IN A CORIOLIS GYRO, AS WELL AS A CORIOLIS GYRO WHICH IS SUITABLE FOR THIS PURPOSE

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BACKGROUND

Field of the Invention

The present invention relates to Coriolis gyroscopes. More particularly, the invention pertains to a method for quadrature-bias compensation in a Coriolis gyro, and to a Coriolis gyro which is suitable for such purpose.

Description of the Prior Art

Coriolis gyros (also referred to as "vibration gyros") are increasingly employed for navigation. Such devices include a mass system that is caused to oscillate. The mass system generally has a large number of oscillation modes, initially independent of one another. A specific oscillation mode of the mass system is artificially excited to operate the Coriolis gyro. Such mode is referred to in the following text as the "excitation oscillation".

Coriolis forces occur that draw energy from the excitation oscillation of the mass system when the Coriolis gyro is rotated and transmit a further oscillation mode of the mass system (referred to below as the "read oscillation"). The read oscillation is tapped

off to determine rotations of the Coriolis gyro, and a corresponding read signal is investigated to determine whether any changes have occurred in the amplitude of the read oscillation which represent a measure of rotation of the Coriolis gyro.

Coriolis gyros may comprise either an open-loop or a closed-loop system. In a closed-loop system, the amplitude of the read oscillation is continuously reset to a fixed value (preferably zero) via respective control loops, and the resetting forces measured.

The mass system of the Coriolis gyro (referred to below as the "resonator") may be of widely differing designs. For example, it is possible to use an integral mass system. Alternatively, it is possible to split the mass system into separate oscillators coupled to one another via a spring system and capable of movements relative to one another. For example, it is known to use a coupled system comprising two linear oscillators (also referred to as a "linear double-oscillator" system). When such a coupled system is used, alignment errors of the two oscillators with respect to one another are unavoidable due to manufacturing tolerances. The alignment errors produce a zero error component in the measured rotation rate signal, the so-called "quadrature bias" (more precisely, a quadrature-bias component).

SUMMARY AND OBJECTS OF THE INVENTION

It is therefore an object of the invention to provide a method and a Coriolis gyro for compensating for a quadrature-bias component as described above.

The present invention addresses the preceding and other objects by providing, in a first aspect, a method for quadrature-bias compensation in a Coriolis gyro whose resonator is in the form of a coupled system comprising a first and a second oscillator. Such method includes determination of the quadrature bias of the gyro and production of an electrostatic field to vary the mutual alignment of the two oscillators with respect to one another. The alignment/strength of the electrostatic field is regulated so that the determined quadrature bias is as small as possible.

In a second aspect, the invention provides a Coriolis gyro in the form of a coupled system comprising a first and a second linear oscillator. Such gyro includes a device for production of an electrostatic field for varying the alignment of the two oscillators with respect to one another.

A device is provided for determination of any quadrature bias of the Coriolis gyro as well as a control

loop for regulating the strength of the electrostatic field as a function of the determined quadrature bias so that the determined quadrature bias is as small as possible.

In a third aspect, the invention provides a Coriolis gyro having a first and a second resonator. The resonators are each in the form of a coupled system including a first and a second linear oscillator.

The first resonator is mechanically or electrostatically connected/coupled to the second resonator so that the two resonators can be caused to oscillate in antiphase with respect to one another along a common oscillation axis.

The foregoing and other features of the invention will become further apparent from the detailed description that follows. Such description is accompanied by a set of drawing figures. Numerals of the drawings, corresponding to those of the written description, point to the features of the invention with like numerals referring to like features throughout.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic illustration of one possible embodiment of a mass system having two linear

oscillators, with corresponding control loops, for exciting the first oscillator.

Figure 2 is a schematic illustration of a possible embodiment of a mass system having two linear oscillators with corresponding measurement and control loops for a rotation rate Ω and a quadrature bias B_Q, as well as auxiliary control loops for compensation of the quadrature bias B_Q.

Figure 3 is a schematic illustration of a mass system in accordance with an embodiment of the invention, which comprises four linear oscillators, with corresponding measurement and control loops for a rotation rate Ω and a quadrature bias B_Q, as well as auxiliary control loops for compensation of the quadrature bias.

Figure 4 is a block diagram of an embodiment of a control system for incorporation into a mass system in accordance with that illustrated in Figure 3 above.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

The method of the invention for quadrature-bias compensation can be applied, in particular, to Coriolis gyros whose resonators are in the form of coupled systems comprising at least one first and one second linear oscillator. The total quadrature bias of the oscillator

system is preferably determined by demodulation of a read signal produced by read electrodes, with 0° and appropriate resetting. It is also possible to determine only a portion of the quadrature bias, produced by the alignment error of the two linear oscillators with respect to one another. (The expression "quadrature bias" covers both alternatives.)

Quadrature bias is thus eliminated at its point of origin i.e., mechanical alignment errors of the two oscillators with respect to one another are compensated by an electrostatic force that acts on one or both oscillators and is produced by the electrostatic field.

In one embodiment, the Coriolis gyro has first and second spring elements, with the first oscillator connected by means of the first spring elements to a frame of the Coriolis gyro and the second oscillator connected by the second spring elements to the first oscillator. The electrostatic field results in a change in the alignment of the first and/or the second spring elements. The alignment of the second spring elements is preferably varied by varying the position/alignment of the second oscillator with the electrostatic field. Analogously, the alignment of the first spring elements is preferably varied by varying the position/alignment of the first oscillator by means of the electrostatic field. The change

in the positions/alignments of the oscillators in such case results in bending the spring elements attached to the oscillators, making it possible to correct corresponding alignment angles of the first spring elements with respect to the second spring elements.

In a particularly preferred embodiment, the electrical field varies the alignment angles of the first and second spring elements so that they are made orthogonal with respect to one another. This compensates for the quadrature-bias (component) produced. If there are any further contributions to quadrature bias, the angle error with respect to orthogonality is adjusted so that the total quadrature bias disappears. The alignment angles of the second spring elements with respect to the first oscillator are preferably varied by the electrostatic field and the alignment angles of the first spring elements with respect to the gyro frame of the Coriolis gyro are unchanged. It is possible to use the electrostatic field to vary only the alignment angles of the first spring elements, or to vary the alignment angles of both the first and the second spring elements.

The invention also provides a Coriolis gyro whose resonator is in the form of a coupled system comprising at least one first and one second linear oscillator. It includes a device for production of an

electrostatic field to vary the alignment of the two oscillators with respect to one another as well as a device for determining quadrature bias caused by alignment errors of the two oscillators with respect to one another and with other coupling mechanisms. A control loop regulates the strength of the electrostatic field as a function of the determined quadrature bias so that the quadrature bias is as small as possible.

If the resonator comprises a first and a second linear oscillator, then the Coriolis gyro preferably has first and second spring elements. The first spring elements connect the first oscillator to the frame of the Coriolis gyro, and the second spring elements connect the second oscillator to the first oscillator. The alignments of the first and second spring elements are preferably at right angles to one another and may be of any desired form.

It has been found to be advantageous for the second oscillator to be attached to or clamped in on the first oscillator "at one end". "Clamped in at one end" can be understood not only in the sense of the literal wording but also in a general sense. In general, attached or clamped in "at one end" means that the force is introduced from the first oscillator to the second oscillator essentially from one "side" of the first oscillator. If,

for example, the oscillator system were designed so that the second oscillator were bordered by the first oscillator and connected to it by means of second spring elements, then the expression "clamped in or attached at one end" would imply that the second oscillator is readjusted for movement of the first oscillator, with the first oscillator alternately "pushing" or "pulling" the second oscillator by means of the second spring elements.

Clamping the second oscillator in at one end on the first oscillator has the advantage that, when an electrostatic force is exerted on the second oscillator as a result of the alignment/position change of the second oscillator, the second spring elements can be slightly curved, thus making it possible, without any problems, to vary the corresponding alignment angle of the second spring elements. If the second oscillator were to be attached to additional second spring elements so that during movement of the first oscillator, the second oscillator were at the same time to be "pulled" and "pushed" by the second spring elements, then this would be equivalent to the second oscillator being clamped in or attached "at two ends" to the first oscillator (with the force being introduced to the second oscillator from two opposite ends of the first oscillator). In such case, the additional second spring elements would produce corresponding opposing forces when an electrostatic field

is applied, so that changes in the alignment angles of the second spring elements could be achieved only with difficulty. However, clamping in at two ends is acceptable when the additional second spring elements are designed so that the influence of these spring elements is small so that all of the spring elements can bend without any problems. That is, the clamping in is effectively at one end.

Depending on the design of the oscillator, clamping in at one end can be effectively provided just by the "influence" (force introduction) of the additional second spring elements being 40% or less. However, this value does not present any limitation on the invention. It is also feasible for the influence of the second spring elements to be more than 40%. For example, clamping in at one end can be achieved by all of the second spring elements that connect the second oscillator to the first oscillator being arranged parallel and on the same plane. All start and end points of the second spring elements are in each case attached to the same ends of the first and second oscillator. The start and end points of the second spring elements may each advantageously be on a common axis, with the axes intersecting the second spring elements at right angles.

If the second oscillator is attached to or

clamped on the first oscillator at one end, then the first spring elements are preferably designed to clamp the first oscillator in on the gyro frame at two ends (the expressions "at one end" and "at two ends" can be used analogously). As an alternative, however, it is possible for the spring elements also to be designed to clamp in the first oscillator at one end. For example, all the first spring elements that connect the first oscillator to the gyro frame of the Coriolis gyro can be arranged parallel and on the same plane as one another, with the start and end points of the first spring elements in each case preferably being located on a common axis. It is equally possible for the spring elements to be designed so that the first oscillator is clamped in on the gyro frame at one end, and the second oscillator is clamped in at two ends by the first oscillator. It is also possible for both oscillators to be clamped in at two ends. For quadrature bias compensation, it has been found to be advantageous for at least one of the two oscillators to be clamped in at one end.

A further embodiment of a Coriolis gyro has a first and a second resonator, each in the form of a coupled system comprising a first and a second linear oscillator. The first resonator is mechanically or electrostatically connected/coupled to the second resonator so that they can be caused to oscillate in

antiphase with respect to one another along a common oscillation axis.

Such embodiment includes a mass system that comprises two double-oscillator systems (i.e., two resonators) or four linear oscillators. Antiphase oscillation of the two resonators with respect to one another results in the center of gravity of the mass system remaining unchanged (provided that the two resonators are appropriately designed). As a result, oscillation of the mass system cannot produce any external vibration that would, in turn, result in disturbances in the form of damping/reflections. Furthermore, external vibrations and accelerations in the direction of the common oscillation axis have no influence on antiphase movement of the two resonators along the common oscillation axis.

For example, the first resonator can be coupled to the second resonator via a spring system. A further option is for the first resonator to be coupled to the second resonator via an electrostatic field. Both couplings can be used alone or in combination. It is sufficient for the two resonators to be formed in a common substrate, so that the mechanical coupling is provided by a mechanical spring connection formed by the common substrate itself.

In this embodiment, the Coriolis gyro advantageously has a device for the production of electrostatic fields to vary the alignment of the linear oscillators with respect to one another, a device for determination of the quadrature bias of the Coriolis gyro, and control loops for regulating the strengths of the electrostatic fields so that the determined quadrature bias is as small as possible.

The configurations of the first and second resonators are preferably identical. In this case, they are advantageously arranged axially symmetrically with respect to one another and to an axis of symmetry at right angles to the common oscillator axis (i.e. the first resonator is mapped by the axis of symmetry onto the second resonator).

In order to assist understanding of the background of the method of the invention, the physical principles of a Coriolis gyro will be explained briefly below, with reference to a linear double-oscillator system.

The Coriolis force can be represented as:

$$\vec{F} = 2m\vec{v}_s x\vec{\Omega} \qquad [1]$$

$\vec{F}$ *Coriolis force*

m *Mass of the oscillator*

$\vec{v}_s$ *Velocity of the oscillator*

$\vec{\Omega}$ *Rotation rate*

If the mass that reacts to the Coriolis force is equal to the oscillating mass, and the oscillator is operated at the natural frequency ω, then:

$$2m\vec{v}_s x\vec{\Omega} = m\vec{a}_c \qquad [2]$$

The oscillator velocity is given by:

$$\vec{v}_s = \vec{v}_{s0} \sin \omega t \qquad [3]$$

where

$\vec{v}_{s0}$ oscillator amplitude

ω natural frequency of the oscillator

The oscillator and Coriolis accelerations are thus given by:

$$\begin{aligned} \vec{a}_s &= \vec{v}_{s0}\omega \cos \omega t \\ \vec{a}_c &= 2\vec{v}_{s0} \sin \omega t \times \vec{\Omega} \end{aligned} \qquad [4]$$

The two acceleration vectors are thus spatially at right angles to one another and are offset through 90° with respect to one another in the time function (spatial and time orthogonality).

These two criteria can be employed to separate oscillator acceleration $\vec{a}_s$ from the Coriolis acceleration

$\vec{a}_c$. The ratio of the abovementioned acceleration amplitudes a_c and a_s is:

$$\frac{a_c}{a_s}=\frac{2\Omega}{\omega} \qquad [5]$$

If the rotation rate is Ω = 5°/h and the natural frequency of the oscillator is f_s = 10 KHz, then:

$$\frac{a_c}{a_s}=7.7\cdot 10^{-10} \qquad [6]$$

For an accuracy of 5°/h, undesirable couplings of the first oscillator to the second oscillator must not exceed $7.7 \cdot 10^{-10}$, or must be constant. If a mass system composed of two linear oscillators coupled to one another via spring elements is employed then the accuracy of the spatial orthogonality between the oscillation mode and the measurement mode is limited due to the alignment error of the spring elements. Achievable accuracy (limited by manufacturing tolerances) is 10^{-3} to 10^{-4}. Time orthogonality accuracy is limited by the phase accuracy of the electronics at, for example, 10 KHz, which can likewise be complied with only to at most 10^{-3} to 10^{-4}. This means that the ratio of the accelerations as defined above cannot be satisfied.

Realistically, the resultant error in the measured acceleration ratio a_c/a_s is:

$$\frac{a_c}{a_s}=10^{-6}\ to\ 10^{-8} \qquad [7]$$

The spatial error results in a so-called quadrature bias B_Q, which, together with the time phase error Δ_ϕ, results in a bias B:

B_Q=6.5•10^6 °/h to 6.5•10^5 °/h

Δ_ϕ=10^{-3} to 10^{-4}

$B=B_Q \bullet \Delta_\phi$=6,500 °/h to 65 °/h [8]

The quadrature bias thus results in a major limitation to measurement accuracy. In this case, it should be noted that the preceding error analysis takes account only of the direct coupling of the oscillation mode to the read mode. Further quadrature bias components also exist and occur, for example, as a result of couplings with other oscillation modes.

Figure 1 illustrates the schematic design of a linear double oscillator 1 with corresponding electrodes including a block diagram of associated evaluation/excitation electronics 2. The linear double oscillator 1 is preferably produced by etching a silicon wafer. It has a first linear oscillator 3, a second linear oscillator 4, first spring elements 5_1 to 5_4, second spring elements 6_1 and 6_2 as well as parts of an intermediate frame 7_1 and 7_2 and a gyro frame 7_3 and 7_4. The second oscillator 4 is mounted within the first oscillator 3 to oscillate, and is connected to it via the

second spring elements 6_1, 6_2. The first oscillator 3 is connected to the gyro frame 7_3, 7_4 by the first spring elements 5_1 to 5_4 and the intermediate frame 7_1, 7_2.

First excitation electrodes 8_1 to 8_4, first read electrodes 9_1 to 9_4, second excitation electrodes 10_1 to 10_4, and second read electrodes 11_1 and 11_2 are also provided. All of the electrodes are mechanically connected to the gyro frame, although electrically isolated. (The expression "gyro frame" refers to a mechanical, non-oscillating structure in which the oscillators are "embedded", e.g., the non-oscillating part of the silicon wafer).

When the first oscillator 3 is excited by the first excitation electrodes 8_1 to 8_4 to oscillate in the X1 direction, such movement is transmitted through the second spring elements 6_1, 6_2 to the second oscillator 4 (alternate "pulling" and "pushing"). The vertical alignment of the first spring elements 5_1 to 5_4 prevents the first oscillator 3 from moving in the X2 direction. However, vertical oscillation can be carried out by the second oscillator 4 as a result of the horizontal alignment of the second spring elements 6_1, 6_2. When corresponding Coriolis forces occur, then the second oscillator 4 is excited to oscillate in the X2 direction.

A read signal that is read from the first read electrodes 9_1 to 9_4 and proportional to the amplitude/frequency of the X1 movement of the first oscillator 3 is supplied, via appropriate amplifier elements 21, 22 and 23, to an analog/digital converter 24. An appropriately digitized output signal from the analog/digital converter 24 is demodulated by a first demodulator 25 and by a second demodulator 26 to form corresponding output signals, with the two demodulators operating with an offset of 90° with respect to one another. The output signal from the first demodulator 25, whose output signal controls a frequency generator 30 so that the signal occurring downstream from the demodulator 25 is regulated at zero, is supplied to a first regulator 27 to regulate the frequency of the excitation oscillation (the oscillation of the mass system 1 in the X1 direction). Analogously, the output signal from the second demodulator 26 is regulated at a constant value (predetermined by the electronics component 29). A second regulator 31 insures that the amplitude of the excitation oscillation is regulated. The output signals from the frequency generator 30 and the amplitude regulator 31 are multiplied by one another at a multiplier 32. An output signal from the multiplier 32, which is proportional to the force to be applied to the first excitation electrodes 8_1 to 8_4, acts not only on a first force/voltage converter 33 but also on a second force/voltage converter 34, which

use the digital force signal to produce digital voltage signals. The digital output signals from the force/voltage converters 33, 34 are converted by first and second digital/analog converters 35, 36 to corresponding analog voltage signals. Such signals are then passed to the first excitation electrodes 8_1 to 8_4. The first and second regulators 27, 31 readjust the natural frequency of the first oscillator 3 and set the amplitude of the excitation oscillation to a specific, predeterminable value.

When Coriolis forces occur, resultant movement of the second oscillator 4 in the X2 direction (read oscillation) is detected by the second read electrodes 11_1, 11_2, and a read signal, proportional to the movement of the read oscillation, is supplied via appropriate amplifier elements 40, 41 and 42 to an analog/digital converter 43 (see Figure 2). A digital output signal from the analog/digital converter 43 is demodulated by a third demodulator 44 in phase with the direct-bias signal and demodulated by a fourth demodulator 45, offset through 90°. A corresponding output signal from the first demodulator 44 is applied to a third regulator 46, whose output signal is a compensation signal that corresponds to the rotation rate Ω to be measured. An output signal from the fourth demodulator 45 is applied to a fourth regulator 47 whose output signal is a compensation signal proportional to the quadrature bias to be compensated. The

output signal from the third regulator is modulated by a first modulator 48, and the output signal from the fourth regulator 47 is modulated in an analogous manner by a second modulator 49, so that amplitude-regulated signals are produced whose frequencies correspond to the natural frequency of the oscillation in the X1 direction ($\sin \cong 0°$, $\cos \cong 90°$). Corresponding output signals from the modulators 48, 49 are added in an addition stage 50, whose output signal is supplied both to a third force/voltage converter 51 and to a fourth force/voltage converter 52. The corresponding output signals for the force/voltage converters 51, 52 are supplied to digital/analog converters 53, 54, whose analog output signals are applied to the second excitation electrodes 10_2 to 10_3, and reset the oscillation amplitudes of the second oscillator 4.

The electrostatic field produced by the second excitation electrodes 10_1 and 10_4 (or the two electrostatic fields produced by the electrode pairs 10_1, 10_3 and 10_2, 10_4) results in an alignment/position change of the second oscillator 4 in the X2 direction, and thus in a change in the alignments of the second spring elements 6_1 to 6_2. The fourth regulator 47 regulates the signal applied to the second excitation electrodes 10_1 and 10_4 so that the quadrature bias included in the compensation signal of the fourth regulator 47 is as small

as possible, or disappears. A fifth regulator 55, a fifth and a sixth force/voltage converter 56, 57 and two analog/digital converters 58, 59 are used for this purpose.

The output signal from the fourth regulator 47, which is a measure of the quadrature bias, is supplied to the fifth regulator 55 that regulates the electrostatic field produced by the two excitation electrodes 10_1 and 10_4 so that the quadrature bias B_Q disappears. An output signal from the fifth regulator 55 is supplied to the fifth and sixth force/voltage converters 56, 57 for this, employing the digital force/output signal from the fifth regulator 55 to produce digital voltage signals that are then converted to analog voltage signals in the analog/digital converters 58, 59. The analog output signal from the analog/digital converter 58 is supplied to the second excitation electrode 10_1 (alternatively to electrode 11_1). The analog output signal from the analog/digital converter 59 is supplied to the second excitation electrode 10_4 (alternatively to electrode 11_2).

As the second oscillator 4 is clamped only by the second spring elements 6_1 to 6_2 (clamped at one end), such alignment of the spring elements can be varied without problem by the electrostatic field. It is additionally possible to provide additional second spring

elements, resulting in the second oscillator 4 being clamped at two ends, provided that such additional elements are appropriately designed to insure that clamping at one end is effective. In order to permit the same effect for the spring elements 5_1, 5_2 (and for the spring elements 5_3, 5_4 as well) the third and fourth spring elements 5_3, 5_4, as well as the first and second spring elements 5_1, 5_2 may be omitted, resulting in the first oscillator 3 being clamped at one end (together with an appropriately modified electrode configuration, not shown). In such a situation, the second oscillator 4 may also be attached to the first oscillator by further spring elements to achieve clamping at two ends.

The electrode arrangements shown in Figures 1 and 2 may be varied. For example, the electrodes identified by the reference numbers 8_1, 9_1, 9_2, 8_2 as well as 8_3, 9_3, 9_4, 8_4 in Figures 1 and 2 may alternatively be combined to form one electrode. An electrode combined in this way may be allocated a plurality of tasks by using suitable carrier frequency methods (i.e., the electrode has read, excitation and compensation functions). The electrodes identified by the reference numbers 11_1, 10_1, 10_3 as well as 11_2, 10_2 and 10_4 can also be combined to form one electrode.

A preferred embodiment of the Coriolis gyro of

the invention as well as its method of operation will be described in more detail with reference to Figure 3, a schematic illustration of a mass system comprising four linear oscillators with corresponding measurement and control loops for rotation rate and quadrature bias, as well as auxiliary control loops for compensation of the quadrature bias. The schematic layout of coupled system 1' comprises a first resonator 70_1 and a second resonator 70_2. The first resonator 70_1 is coupled to the second resonator 70_2 by a mechanical coupling element (a spring) 71. The first and the second resonator 70_1, 70_2 are formed in a common substrate and may be caused to oscillate in antiphase with respect to one another along a common oscillation axis 72. The first and the second resonators 70_1, 70_2 are identical, and are mapped onto one another via an axis of symmetry 73. The design of the first and second resonators 70_1, 70_2 has been explained in conjunction with Figures 1 and 2 and will therefore not be explained again. (Identical and mutually corresponding components or component groups are identified by the same reference numbers with identical components associated with different resonators being identified by different indices.)

A major difference between the double oscillators shown in Figure 3 and those shown in Figures 1 and 2 is that some of the individual electrodes are

physically combined to form one overall electrode. For example, the individual electrodes identified by the reference numbers 8_1, 8_2, 9_1 and 9_2 in Figure 3 form a common electrode. Further, the individual electrodes identified by the reference numbers 8_3, 8_4, 9_3 and 9_4 form a common electrode, those with the reference numbers 10_4, 10_2, 11_2 as well as the reference numbers 11_1, 10_3 and 10_1 each form an overall electrode. The same applies in an analogous manner to the other double-oscillator system.

During operation of the coupled system 1' in accordance with the invention, the two resonators 70_1, 70_2 oscillate in antiphase along the common oscillation axis 72. The coupled system 1' is thus not susceptible to external disturbances or to those emitted by the coupled system 1' itself into the substrate in which the resonators 70_1 and 70_2 are mounted.

When the coupled system 1' is rotated, the second oscillators 4_1 and 4_2 are deflected in mutually opposite directions (i.e., the X2 direction and opposite to the X2 direction). When an acceleration of the coupled system 1' occurs, the second oscillators 4_1, 4_2 are each deflected in the same direction, i.e., in the same direction as the acceleration provided that such acceleration is in the X2 direction, or in the opposite direction. Accelerations and rotations can thus be

measured simultaneously or selectively. Quadrature bias compensation can be carried out during the measurement process in the resonators 70_1, 70_2. However, this is not absolutely essential.

In principle, it is possible to operate the coupled system 1' on the basis of the evaluation/excitation electronics 2 described with reference to Figures 1 and 2. An alternative method (carrier frequency method) is instead used in the embodiment of Figure 3. Such operating method will be described below.

The evaluation/excitation electronics 2 identified by the reference number 2' include three control loops: a first control loop for excitation and/or control of an antiphase oscillation of the first oscillators 3_1 and 3_2 along the common oscillation axis 72, a second control loop for resetting and compensation of the oscillations of the second oscillator 4_1 along the X2 direction, and a control loop for resetting and compensation of the oscillations of the second oscillator 4_2 along the X2 direction. The three described control loops include an amplifier 60, an analog/digital converter 61, a signal separation module 62, a first to third demodulation module 63_1 to 63_3, a control module 64, an electrode voltage calculation module 65, a carrier

frequency addition module 67, and a first to sixth digital/analog converter 66_1 to 66_6.

Carrier frequencies can be applied to the electrodes 8_1 to 8_8, 9_1 to 9_8, 10_1 to 10_8 and 11_1 to 11_4 for tapping excitation of the antiphase oscillation or of the oscillations of the second oscillators 4_1, 4_2. This may be accomplished in a number of ways. They include a) using three different frequencies, with one frequency associated with each control loop, b) using square-wave signals with a time-division multiplexing method, and c) using random phase scrambling (stochastic modulation method).

The carrier frequencies are applied to the electrodes 8_1 to 8_8, 9_1 to 9_8, 10_1 to 10_8 and 11_1 to 11_4 via the associated signals UyAo, UyAu (for the second oscillator 4_1) Uxl, Uxr (for the antiphase resonance of the first oscillators 3_1 to 3_2) and UyBu and UyBo (for the second oscillator 4_2), that are produced in the carrier frequency addition module 67 and excited in antiphase with respect to the abovementioned frequency signals. The oscillations of the first and second oscillators 3_1, 3_2, 4_1 and 4_2 are tapped off via those parts of the gyro frame identified by the reference numbers 7_7, 7_9, 7_{11} and 7_{13}, (used as tapping electrodes in addition to their function as suspension points for the mass system). For this, the two resonators 70_1, 70_2 are preferably designed to be

electrically conductive, with all of the frames, springs and connections. The signal, tapped off by means of the gyro frame parts 7_7, 7_9, 7_{11} and 7_{13} and supplied to the amplifier 60, contains information about all three oscillation modes. It is converted by the analog/digital converter 61 to a digital signal supplied to the signal separation module 62.

The assembled signal is separated into three different signals in the signal separation module 62: x (which contains information about the antiphase oscillation), yA (which contains information about the deflection of the second oscillator 4_1) and yB (which contains information about the deflection of the second oscillator 4_2). The signals are separated differently in accordance with the type of carrier frequency method used (see a) to c) above). Separation is carried out by demodulation with the corresponding signals of the carrier frequency method. The signals x, yA and yB are supplied to the demodulation modules 63_1 to 63_3 that demodulate them with an operating frequency of the antiphase oscillation for 0° and 90°. The control module 64 and the electrode voltage calculation module 65 for regulation/calculation of the signals Fxl/r or Uxl/r, respectively, are preferably configured analogously to the electronics module 2 of in Figure 1. The control module 64 and the electrode voltage calculation module 65 (for

regulation/calculation of the signals FyAo/u, UyAo/u, and FyBo/u, UyBo/u) are preferably designed analogously to the electronics module 2 of Figure 2. The only difference is that the signals for resetting the rotation rate and the quadrature after the multiplication by the operating frequency are passed together with DC voltages for the quadrature auxiliary regulator to a combined electrode pair. The two signals are therefore added, so that calculation of the electrode voltages includes the resetting signals for oscillation frequency and the DC signal for quadrature regulation as well as frequency tuning. The electrode voltages Uxl/r, UyAo/u and UyBo/u calculated in this way are then added to the carrier-frequency signals and passed jointly via the analog/digital converters 66_1 to 66_6 to the electrodes.

Figure 4 is a block diagram of an embodiment of a control system for incorporation into a mass system in accordance with Figure 3. It shows one preferred embodiment of the control system identified by the reference number 64 in Figure 3. The control system 64 includes a first to third part 64_1 to 64_3. The first part 64_1 has a first regulator 80, a frequency generator 81, a second regulator 82, an electronics component 83, an addition stage 84 and a multiplier 85. The operation of the first part corresponds essentially to that of the electronics module 2 of Figure 1 and will therefore not be

described once again. The second part 64_2 has a first regulator 90, a first modulator 91, a second regulator 92, a second modulator 93 and a third regulator 94. A first and a second addition stage 95, 96 are also provided. A rotation rate signal Ω can be determined at the output of the first regulator 90, and an assembled signal comprising the compensation of the quadrature bias B_Q and an acceleration A can be determined at the output of the third regulator 94.

The third part 64_3 of the control system 64 has a first regulator 100, a first modulator 101, a second regulator 102, a second modulator 103 and a third regulator 104. A first and a second addition stage 105, 106 are also provided. A rotation rate signal Ω with negative mathematical sign can be tapped off at the output of the first regulator 100 and an assembled signal comprising the compensation of the quadrature bias B_Q with negative mathematical sign and an acceleration signal A can be tapped off at the output of the third regulator 104. The method of operation of the second and of the third parts 64_2 and 64_3 corresponds to that of the electronics module 2 illustrated in Figure 2, and will therefore not be explained again.

Only the signals for resetting rotation rate and quadrature, after multiplication by the operating frequency, are passed, together with the DC voltages for

the quadrature auxiliary regulator, to a combined electrode pair. The two signals are therefore added so that the calculation of the electrode voltages includes the reset signals for oscillation frequency and the DC signal for quadrature regulation. The electrode voltages Uxl/r, UyAo/u and UyBo/u thusly calculated are then added to the carrier frequency signals and jointly passed via the analog/digital converters 66_1 to 66_6 to the electrodes.

The carrier frequency methods described above with antiphase excitation have the advantage that a signal is applied to the amplifier 60 only when the linear oscillators 3_1, 3_2, as well as 4_1 and 4_2, are deflected. The frequency signals used for excitation may be discrete frequencies or square-wave signals. Square-wave excitation is preferred, as it is easier to produce and process.

Linear double oscillators are distinguished by particularly high quality due to linear movement on the wafer plane. Compensation for the quadrature bias linear resonators in which at least one oscillator is clamped in at one end can be achieved, according to the invention, globally by adjustment of the orthogonality of the springs. This is achieved by varying the angle of the springs of the oscillator, clamped in at one end, by means of a DC voltage, such that the measured quadrature bias B_Q

becomes zero. As described above, a corresponding control loop is used for this purpose to regulate the abovementioned DC voltage so that $B_Q = 0$. The control loop compensates for quadrature bias at the point of origin and improves the accuracy of linear oscillation gyros by a number of orders of magnitude. The linear oscillators of a resonator are preferably each operated at double resonance.

While the invention has been described with reference to a presently-preferred embodiment, it is not limited thereto. Rather, this invention is limited only insofar as it is defined by the following set of patent claims and includes within its scope all equivalents thereof.